LASE Measurements of Water Vapor, Aerosols, and Clouds During the NASA CAMEX-4 Experiment

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During the CAMEX-4 (Convection and Moisture Experiment-4) field experiment, which will be conducted over the Atlantic Ocean and Gulf of Mexico in August-September 2001, we will operate the Lidar Atmospheric Sensing Experiment (LASE) Differential Absorption Lidar (DIAL) system to remotely measure the distributions of water vapor, aerosol, and clouds throughout the troposphere from the NASA DC-8 aircraft. These lidar data will provide high resolution cross sections of water vapor (330 meter in vertical, 20 km in horizontal) and aerosols (30 meters in vertical, 200 meters in horizontal) from the surface to near the tropopause (~15-16 km) along the DC-8 flight tracks.

LASE measurements in the hurricane environment are important because deficiencies in the knowledge of tropical humidity fields hamper efforts to model moisture and diabatic processes in hurricanes. Water vapor is a key element in understanding processes related to evaporation, cloud formation, the release of latent heat, and precipitation. Current operational forecast models have not included moisture processes due, mainly, to the lack of accurate humidity data with sufficient vertical and horizontal resolution. LASE measurements acquired during CAMEX-4 provide the opportunity to assess the impact of high temporal and vertical resolution water vapor measurements on hurricane forecasts.

Real-time (preliminary) water vapor, aerosol, and cloud profiles will be derived from the LASE data to rapidly assess the atmospheric conditions and assist in the planning and execution of these aircraft flights. The LASE team will provide preliminary real-time and post-flight color images depicting the distributions of water vapor and aerosol backscatter to the science investigators to assist in flight planning as needed. Preliminary digital data of the LASE water vapor, aerosol and cloud profile measurements will also be provided to the science investigators during the CAMEX-4 mission. High resolution cross-sections of water vapor distributions (330 m vertical, 20 km horizontal) and aerosol backscattering and scattering ratios (30 m vertical and 200 m horizontal) will be derived after post-processing following the field experiment. Comparisons of water vapor and aerosol profiles will also be made using the LASE, in-situ, and ground-based remote sensing data. Following the mission, in-situ and remotely sensed temperature and aerosol data acquired by aircraft and ground based sensors will be combined with the LASE data to better characterize the thermodynamic and aerosol environments of the tropical storms. We shall also use the LASE water vapor profiles to assess the water vapor measurement capabilities of the DC-8 and ER-2 dropsondes. The LASE data will also be used by researchers at Florida State University to assess the impact of assimilating high spatial and temporal resolution measurements of water vapor on model forecasts of hurricane movement and intensification.

Characteristics of the LASE System

LASE is a differential absorption lidar (DIAL) system that operates in the 815 nm region. The LASE system was developed as an autonomous DIAL system and was originally designed and operated from the Q-bay of the high altitude NASA ER-2 aircraft. LASE demonstrated autonomous operating capability, reliability of operation, and accuracy for profiling water vapor over the entire troposphere during the 1995 LASE Validation Experiment. LASE has since participated in the Tropospheric Aerosol Radiative Forcing Experiment (TARFOX) held over the Atlantic Ocean east of Wallops Island, VA in July 1996, the 1997 Southern Great Plains Experiment (SGP97) conducted in Oklahoma during June-July 1997 as part of the NASA Hydrology Program, the Convection and Moisture Experiment-3 (CAMEX-3) conducted during August-September 1998 over the Atlantic Ocean east of Florida in August, the PEM Tropics B Experiment conducted over the tropical Pacific Ocean during March-April 1999, the SAGE-III Ozone Loss and Validation Experiment (SOLVE) over the Arctic during December 1999-March 2000, and the ARM FIRE Water Vapor Experiment (AFWEX) over the Dept. of Energy Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site in Oklahoma during December 2000. LASE has been reconfigured to fly on the NASA DC-8 where it acquires data simultaneously in the nadir and zenith pointing modes to permit coverage over the troposphere.

The LASE system uses a Ti:sapphire-based laser system as transmitter. This laser system consists of a double-pulsed Ti:sapphire laser that operates in the 815-nm absorption band of water vapor and is pumped by a frequency-doubled flashlamp-pumped Nd:YAG laser. The wavelength of the Ti:sapphire laser is controlled by injection seeding with a diode laser that is frequency locked to a water vapor line using an absorption cell. The LASE detector system consists of two silicon avalanche photodiodes (Si:APD) and three digitizers to cover a large signal dynamic range (10^6), and the signal processor system is designed to be relatively insensitive to rapid changes in signal levels. The LASE data system on the DC-8 will enable real-time and post-flight analyses on-board the aircraft. A 275 MHz Alpine w/DEC Alpha CPU with 128 MB memory 12 GB data storage is used for data processing and analysis. Adjustments to the instrument will be made on-board the aircraft using on-board test equipment to maintain optimum performance.

In the current mode of operation LASE operates locked to a strong water vapor line and electronically tunes to any spectral position on the absorption line to choose the suitable absorption cross-section for optimum measurements over a range of water vapor concentrations in the atmosphere. In addition, LASE can operate over two or three water vapor concentration regions to cover a large altitude region in the troposphere. This unique method of operation permits rapid and more flexible absorption cross-section selection capability for water vapor measurements over the entire troposphere in a single pass.

Figure 1 shows a schematic diagram of LASE. Figure 2 shows LASE on the DC-8 during the CAMEX-3 mission.

LASE Measurement Capabilities

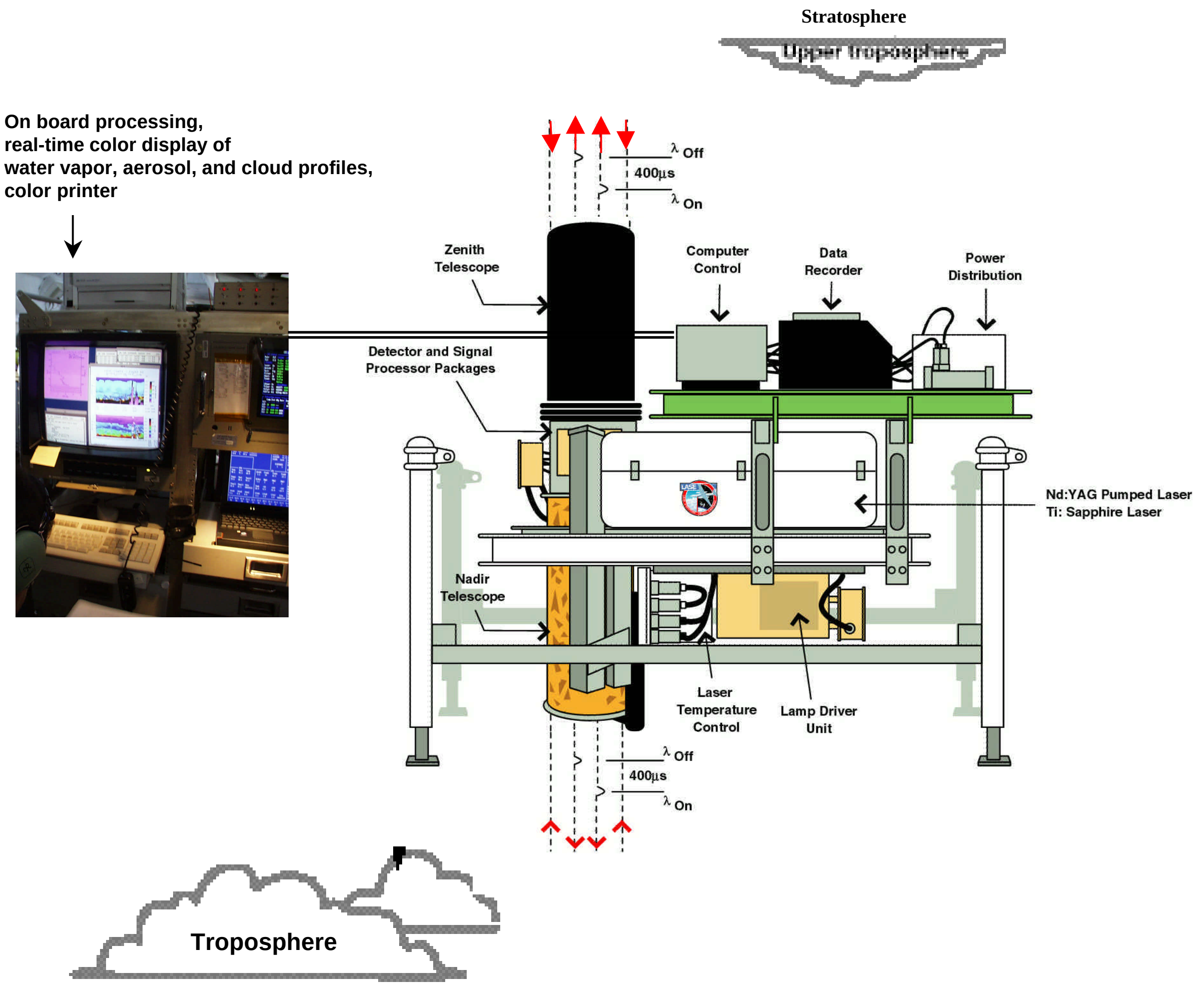

Figure 1. Schematic diagram of LASE as configured inside the DC-8 for CAMEX-3 and CAMEX-4 deployments.

During the September 1995 LASE Validation Field Experiment, LASE measurements were compared with a number of in-situ and remote sensors from the ground and other aircraft (Browell et al., 1997). During the Validation Experiment LASE demonstrated the capability to measure water vapor distributions over the entire troposphere with values ranging from about 15 g/kg near the ocean surface to about 0.01 g/kg near the tropopause in the tropical region and at mid-latitudes. The LASE water vapor measurements were found to have an accuracy of better than 6% or 0.01 g/kg, whichever is greater, across the entire troposphere. The projected water vapor and aerosol measurement capabilities of LASE during the CAMEX-4 mission are listed in Table 1.

Figure 2. (Top) View of LASE (looking aft) on DC-8 during CAMEX-3 mission. (Bottom) View of LASE (looking forward) on DC-8 during CAMEX-3 mission.

Table 1. LASE Water Vapor and Aerosol Profiling Capability on NASA DC-8

WATER VAPOR	
Altitude coverage	~100 m above surface to tropopause (~15-16 km)
Measurement capability	Daytime and nighttime
Measurement range	0.01 g/kg to 20 g/kg
Accuracy (mixing ratio)	Better than 10% (or 0.01 g/kg)
Resolution (nominal)*	20.0 km (horizontal) 330 m (vertical)
AEROSOL BACKSCATTER (815 nm)	
Altitude coverage	30 m above surface to tropopause (15-18 km)
Measurement capability	daytime and nighttime
Measurement range	0.2 to > 100 (aerosol scattering ratio (S/R))
Precision	better than 3% (or 0.2 S/R)
Resolution (nominal)	200 m (horizontal) 30 m (vertical)

The ability of LASE to acquire high resolution water vapor and aerosol data in the hurricane environment was demonstrated during the previous CAMEX-3 mission. During CAMEX-3, which was conducted over the Atlantic Ocean and Gulf of Mexico during August-September, LASE made the first extensive measurements of moisture, aerosol, and cloud distributions over four hurricanes: Bonnie, Danielle, Earl, and Georges. LASE measurements showed the extent of the dry subsiding air ahead of a hurricane, the extent of the inflow of very moist air in the lower troposphere into a hurricane, the distribution of clouds, rain, and water vapor associated with the hurricane rain bands, and the detailed moisture distribution across the eye of a hurricane. Figure 3 shows LASE data acquired ahead of tropical storm Bonnie before this storm intensified into a hurricane and made landfall on the North Carolina coast. Figure 4 shows additional LASE data acquired over Hurricane Bonnie just prior to landfall. Figure 5 shows LASE data acquired in the vicinity of Hurricane Georges.

These LASE data have been used by researchers at Florida State University in an adaptive observation strategy to assess the impact of assimilating targeted digital aircraft weather data on hurricane forecasting. Although the CAMEX-3 flights permitted only a limited number of opportunities to assess this adaptive observational strategy, model runs that included the LASE CAMEX-3 data showed a significant (~50%) improvement in 48 to 72 hour forecasts of moisture (Bensman, 2000). When LASE data were used along with dropsonde observations, the hurricane intensity and its structure were well represented and the forecast tracks were closer to the corresponding best observed hurricane tracks (Rizvi et al., 2001). The LASE measurements for CAMEX-4 represent an additional opportunity to provide the high resolution water vapor data required to assess and improve hurricane forecast models.

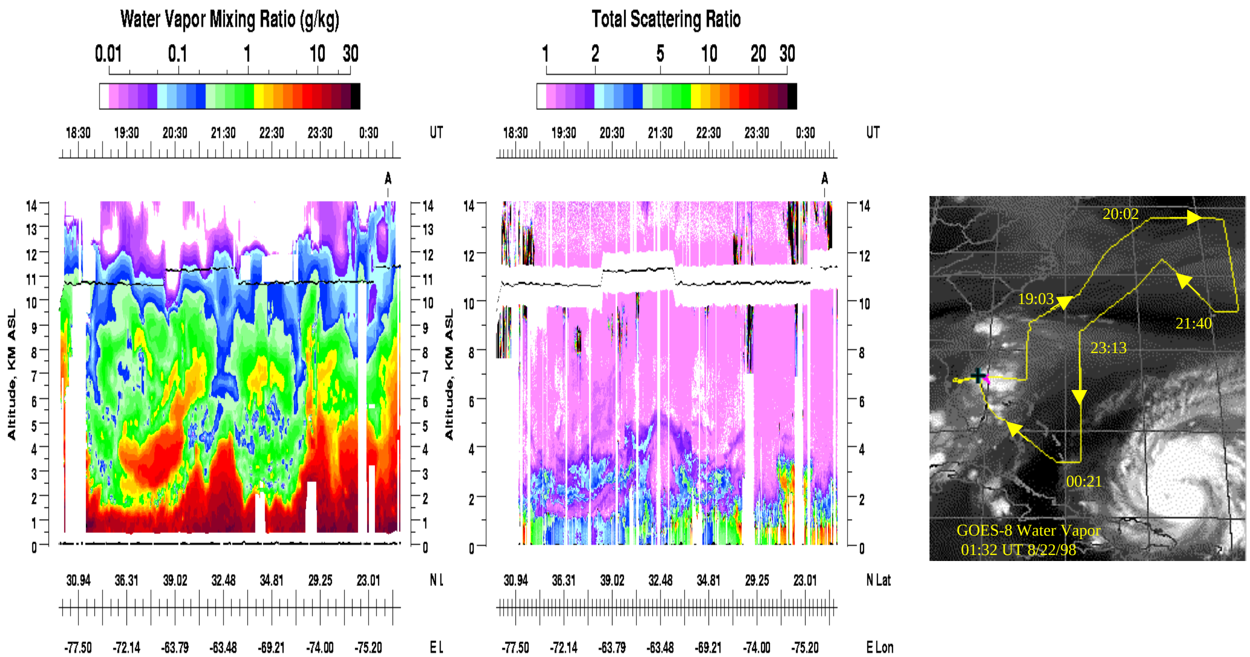

Figure 3. (Left) LASE water vapor mixing ratio profiles acquired during CAMEX-3 Flight 7 on August 21-22, 1998. Nadir and zenith water vapor profiles have been combined in this image. The DC-8 in situ laser hygrometer measurements have been used to interpolate between the LASE nadir and zenith measurements. The DC-8 flight altitude is shown by the black line. (Middle) Same except showing the LASE total scattering ratio measurements. Cirrus clouds have high scattering ratios and appear as the black areas above about 8 km. Aerosol scattering is confined mainly to altitudes below 5 km. (Right) GOES-8 Water vapor imagery showing the DC-8 flight track in relation to (then) tropical storm Bonnie. The DC-8 flew to the north and west of tropical storm Bonnie to gather data to help improve short and medium term hurricane track predictions, and to study the influence of synoptic scale fields on vortex track and intensity. LASE measurements show considerable variation in water vapor during this flight. Note the correspondence between the LASE water vapor profiles and the water vapor field shown in the GOES image.

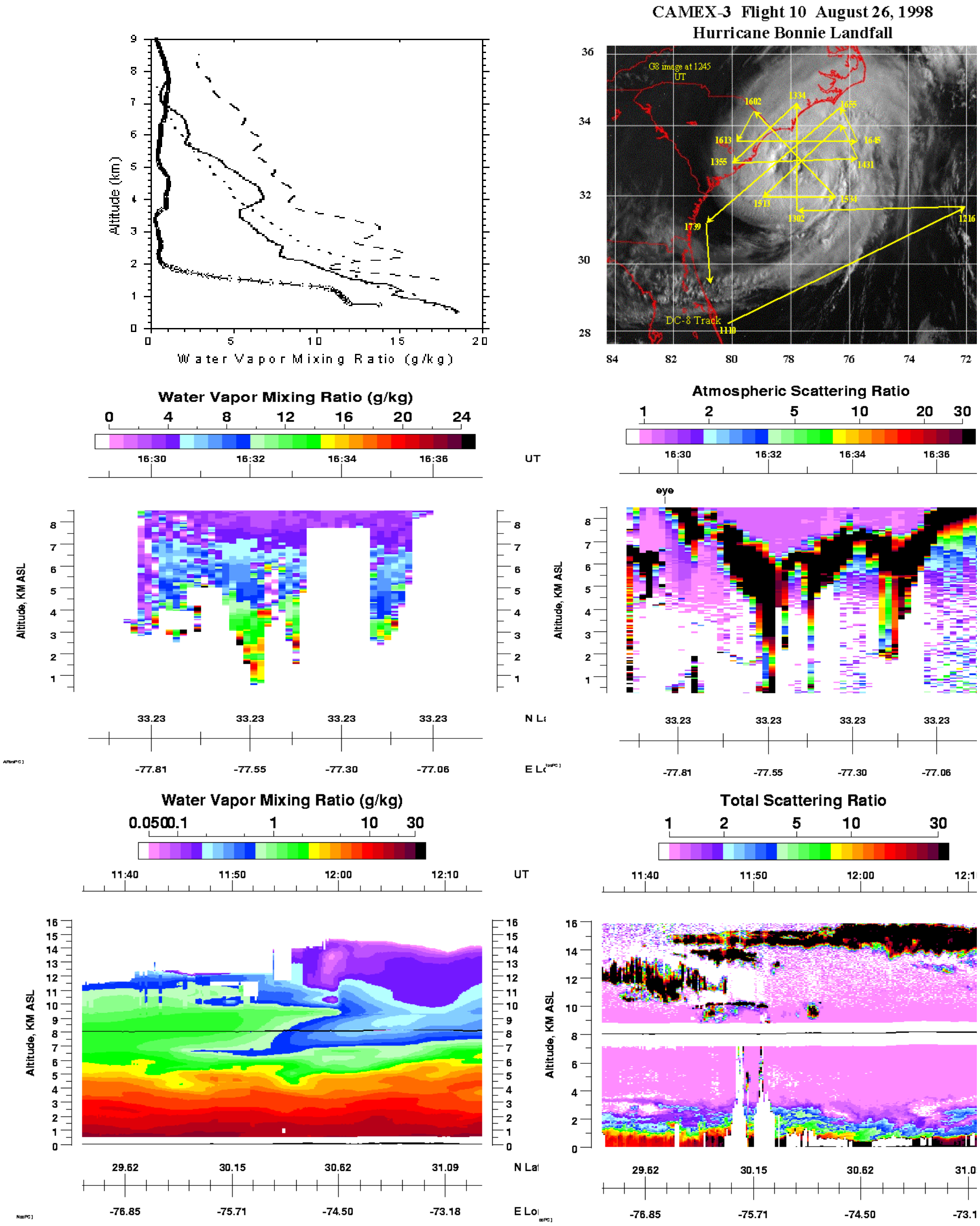

Figure 4. (Top Left) A comparison of LASE measurements of water vapor associated with Hurricane Bonnie: regions of subsidence (diamonds); rainband (solid line), edge of hurricane (dotted line); and eye region (dashed line). (Top Right) GOES image showing DC-8 flight track on August 26, 1998 when Bonnie made landfall. (Middle Left) LASE water vapor measurements in Bonnie's eye. (Middle Right) LASE total scattering ratio measurements in Bonnie's eye. Note that the eye still had considerable cloudiness at this time. (Bottom Left) LASE water vapor measurements acquired southeast of Bonnie. (Bottom Right) LASE total scattering ratio measurements acquired southeast of Bonnie.

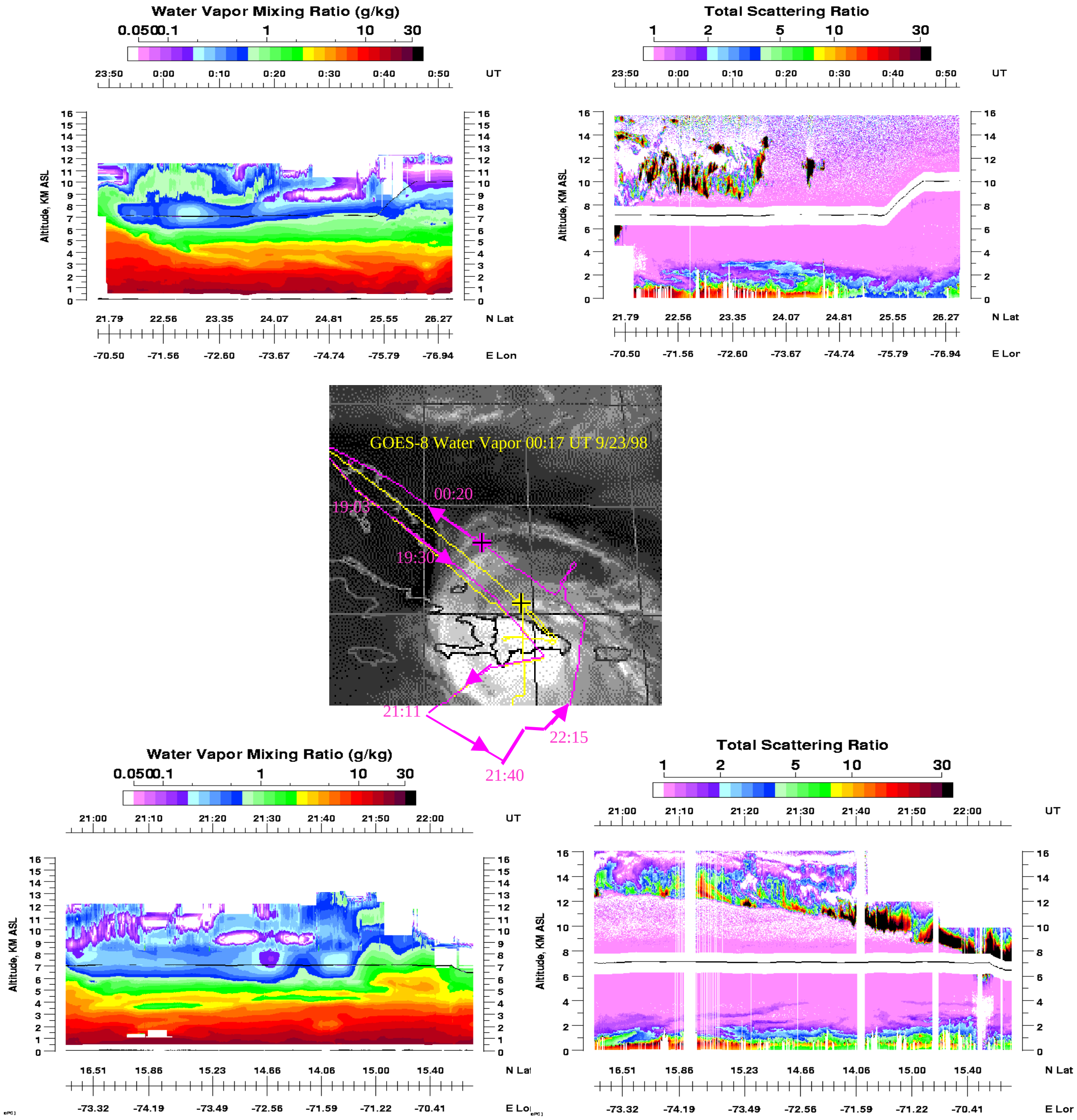

Figure 5. (Top Left) LASE water vapor measurements acquired on September 22-23, 1998 when the DC-8 traveled northwest away from Hurricane Georges. (Top Right) same except for total scattering ratio. (Middle) GOES-8 water vapor image showing Hurricane Georges. The DC-8 flight track is shown in violet. (Bottom Left) LASE water vapor measurements acquired south of Georges. (Bottom Right) LASE total scattering ratio measurements acquired south of Georges.

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